Benefits of 8x8 Wi-Fi Home Gateways

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WHITEPAPER

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Quantenna (Nasdaq: QTNA) is the global leader and innovator of high performance Wi-Fi solutions. Founded in 2006, Quantenna has demonstrated its leadership in Wi-Fi technologies with many industry firsts in the market. Quantenna continues to innovate with the mission to perfect Wi-Fi by establishing benchmarks for speed, range, efficiency and reliability. Quantenna takes a multidimensional approach, from silicon, system to software for Wi-Fi networks and provides solutions for OEMs and service providers worldwide. For more information, visit www.quantenna.com.

1.0 Introduction

Data usage and media consumption habits within a home have dramatically changed in recent times. The proliferation of over-the-top (OTT) streaming services and increased penetration of mobile devices with high resolution displays have resulted in viewing habits that are personalized to each user rather than an entire family. This in turn has increased the minimum aggregate Wi-Fi data rate need to multi-hundreds of Mbps. Furthermore, these devices can be located anywhere within the home and hence it is paramount to ensure whole home coverage.

Within homes, Multi-input Multi-output (MIMO) Wi-Fi gateways and clients have been deployed for nearly a decade starting with the 802.11n standard. It is well known that a wireless MIMO system can improve the data rate of single user using multiple antennas for transmission and reception. This is done by spatially multiplexing the data onto a number of parallel streams, transmitting them simultaneously in the same frequency band, and separating them at the receiver using multiple antennas. In general, given a sufficiently multi-path rich propagation medium, a communication system consisting of a Wi-Fi device with M transmitters and another Wi-Fi device with N receivers can achieve a data rate increase that is linearly proportional to min(M, N). If M > N, additional performance benefit can be obtained in the form of transmit beamforming and if N > M, then the excess receivers can be used to provide receive diversity gain. Figure 1 shows the Shannon capacity for various MIMO configurations when M=N (i.e. the channel from each transmitter to the receiver is independently and identically distributed complex Gaussian random variables with zero mean and unit variance). At high signal to noise ratios, it is seen that the capacity grows linearly with the number of antennas.

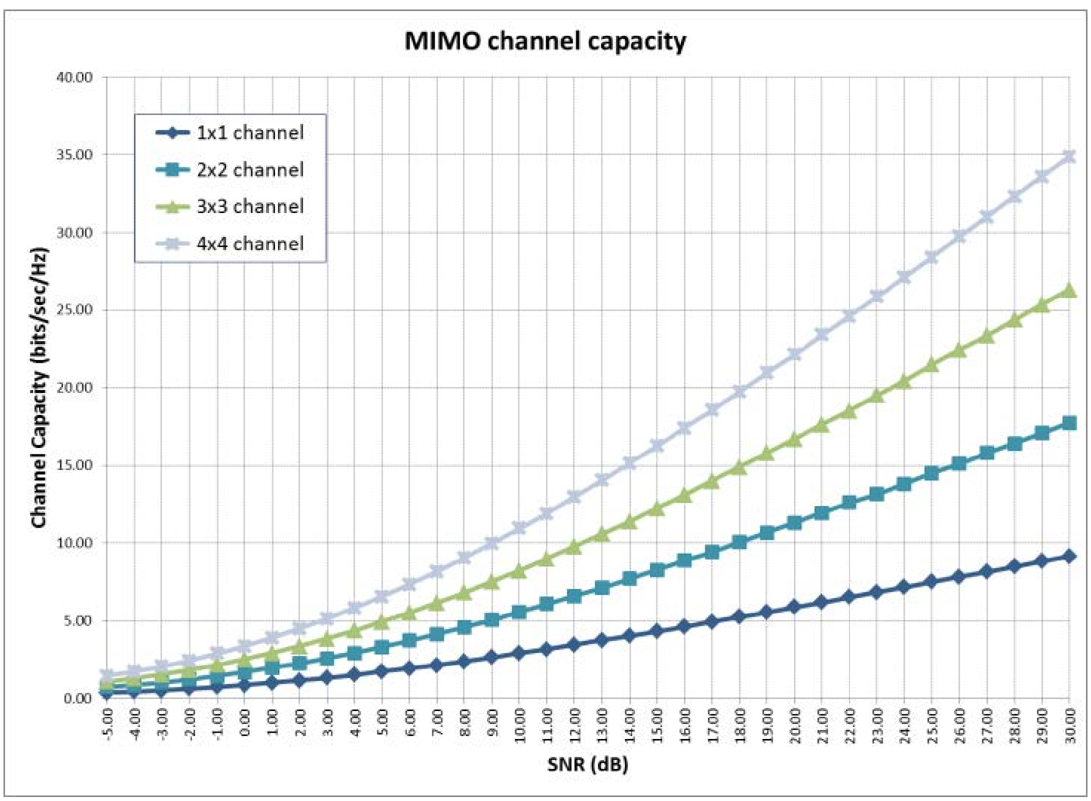

Figure 1. Shannon Capacity of an NxN MIMO system

While the initial deployments of Wi-Fi with MIMO capability focused on a single user, it has become apparent that these data rate gains in real life are not scaling as expected. This is because most client devices, especially mobile, have at most 2 transmitters and/or receivers limiting the spatial multiplexing gain to at most 2. However, the advent and rapid adoption of so called multi-user MIMO (MU-MIMO) Wi-Fi promises to leverage the benefits of MIMO to multiple devices simultaneously. In multi-user MIMO, if a gateway has M transmitters, it can transmit simultaneously to K clients, each equipped with N_1, N_2, N_3, …, N_k receivers, as long as $N_1+N_2+…+N_k$ does not exceed M on the downlink. Similarly, in the uplink multi-user MIMO case, K client devices each equipped with M_1, M_2, M_3,…M_k transmitters can transmit to a gateway with N receivers as long as $M_1+M_2+M_3+…+M_k$ is at most equal to N. Thus MU-MIMO is needed to exploit the MIMO capability at a home gateway to the fullest extent. In this white paper, we will focus on the benefits of higher order MIMO when MU-MIMO is utilized.

Current home gateways are being deployed with 4 transmitters and 4 receivers (4x4 MIMO home gateway). In order to improve overall home coverage, repeaters and/or multiple Wi-Fi nodes that are capable of networking with each other are subsequently added. However, use of repeaters often come at the cost of lowering the network capacity because of the half duplex nature of the repeaters

A better solution is to have home gateways support 8x8 MU-MIMO. This allows support of multiple MU-MIMO clients within the home while providing improved coverage and higher network capacity. This 8x8 system is shown to offer the following key benefits over a 4x4 system for a typical home using simulation models and real life measured data in the following manner:

- **Single User Data Rate** – An 8x8 AP can outperform a 4x4 AP in its single-user throughput. Overall throughput is significantly improved within a 3000 sq. ft. home, resulting in an average of at least 60% improvement in the achievable throughput. About 24% of a 3000 sq. ft. home shows more than 100% improvement.
- **Home Coverage** – An 8x8 AP has a larger coverage area than its 4x4 counterpart. Given a minimum bit rate of 100 Mbps, 35% more homes would require a repeater with 4x4 AP deployment compared to 8x8 AP deployment.
- **MU-MIMO** – An 8x8 AP has significantly better MU-MIMO performance and unparalleled scaling with group size. MU-MIMO gains scale up to 4 clients for 8x8 but caps at 2 clients for 4x4 deployments.
- **Repeater Configuration** - Minimizing the need for repeater/mesh within a home over 4x4 thus providing the most economical deployment for service providers within the home.

The next two sections describe the simulation model and summarize the simulation results showing the performance comparison between 8x8 and 4x4 APs in terms of coverage, speed test throughput and network capacity with and without repeaters. The last section describes a real life test for MU-MIMO performance using a real network in a test house.

2.0 Simulator Description

A Quantenna simulator was used to model Wi-Fi network behavior in a typical home with access points (AP) and Repeaters. Network behavior includes the coverage and speed-test rates supported in the home, link budget analysis, airtime distribution and network capacity calculation for a given set of AP, Repeater, and Stations (STA) in a home. The simulator is implemented using Matlab and models the network at a flow level using medium access (MAC) and physical (PHY) layer models. The input-output model is shown in Figure 2 and described below.

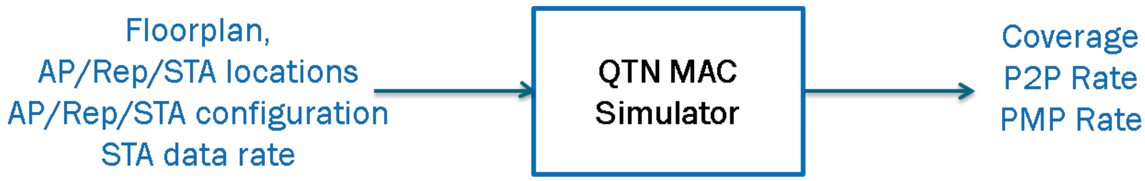

Figure 2. Input-Output model of the MAC Simulator

2.1 Input Variables

The input to the simulator is a floorplan with the location of the AP, repeaters (if present) and the stations. The floorplan is described in terms of the internal and external walls. The location of the AP is constrained to be near an external wall, with an assumption that the broadband connection entry point is located there. The location of the repeaters is constrained to be near any wall. The STAs are located based on typical use cases in homes. The MIMO configuration of the AP/Repeater/STAs, band (2.4G or 5G), BW (20, 40, 80, 160 MHz) of the links between the AP-Repeater, Repeater-STA, AP-STA and the required data rate for each STA are configurable. In addition, the mode of operation: full duplex (FD) or half duplex (HD) and single user (SU) or multi-user (MU) operation is configurable for the AP-Repeater link.

2.2 Output Metrics

The simulator calculates the point-to-point (P2P) or point-to-multi-point (PMP) UDP downlink (DL) rate supported by each link specified. For a P2P calculation, usually a grid of evenly distributed STAs all over the floorplan is used. The simulator can also calculate the PMP rate supported by a specified set of STAs. The location of the AP/repeaters can be found automatically (best location dependent on a metric, e.g. coverage or average P2P rate etc.) or can be fixed (the results in the later sections uses fixed locations). During the P2P and PMP simulations, the model also indicates the STAs or regions in the floorplan that are not covered by the current AP/Repeater combination.

2.3 Simulation Procedure

The simulation procedure is outlined in Figure 3. The path-loss is calculated using the IEEE 802.11ax model. All walls in the home are assumed to have the same construction so as to have the same attenuation for Wi-Fi signals. From the location of the transmitter (TX) and receiver (RX), the path-loss of the link is calculated, which is a function of the distance between the endpoints, number of walls and floors that the path crosses. The RSSI is also calculated from the AP and different available repeaters to decide how is the STA connected to the AP (directly or through a repeater). The STA decides on which AP or Repeater to associate based on the best RSSI. This behavior emulates simple association logic where the AP and Repeaters share the SSID. The clients are assumed to be stationary and once connected to a Repeater or AP, the routing of the packets is fixed for the duration of the traffic. If the RSSI is too low to support even MCS0, the STA is said to be disconnected. Then, experimental range-vs-rate (RvR) data is used to convert the path-loss to a physical layer rate that the link can support. At this point for P2P rate calculation, timing calculation is done for packet aggregation and overhead for various UDP, IP, MAC and PHY headers including the modifications for single or multi-hop links. For a link through a repeater, the repeater buffer size is configurable to allow for delays due to scheduling. For PMP rate calculation, depending on the required data rate for the STAs, the airtime required is first calculated and then the flows are scheduled based on the fairness criteria. Airtime fairness is used for the results shown later.

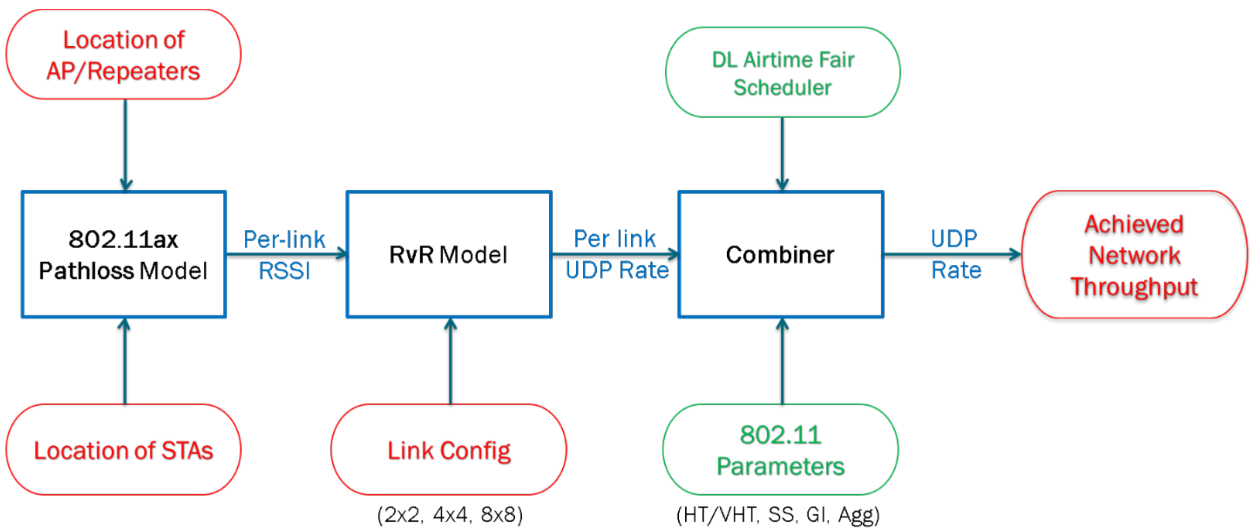

Figure 3. Steps involved in the MAC simulator.

3.0 Simulation of Network Gains

From the results of simulations done over different floorplans varying in size from 2000 sq. ft. to 4000 sqft. the main conclusion is that, an 8x8 AP offers significantly improved performance for many different metrics (coverage, speed test performance, network performance, airtime usage, and scalability etc.).

3.1 Repeater requirements for typical homes

The experimental RvR indicates that there is around a 5-6 dB gain for using an 8x8 AP as compared to a 4x4 AP in the linear region of the curve (approximately in the 75 – 110 dB path loss range) as shown in Figure 4. This suggests that any link in the home in this range of path-loss will get a boost of 5-6 dBs in performance by switching to an 8x8 AP. As example, Figure 4 shows 5dB of pathloss difference between 8x8 and 4x4 Aps for a 100Mbps connection to a 2x2 STA.

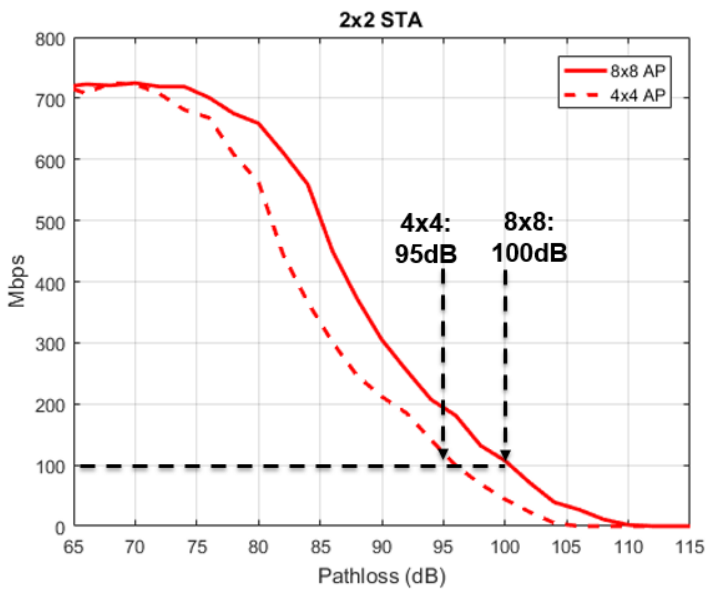

Figure 4. Typical RvR for a 2x2 STA.

We have obtained real life path loss from 7000 actual homes using Quantenna MAUI cloud platform and the data collected is shown in Figure 5. This data shows the path loss on the Y axis and the percentage of the total number 7000 homes that have a specific path loss. This data when combined with Figure 4 suggests that to support a rate of 100Mbps within the home, about 45% of the 4x4 homes will be able to sustain this speed whereas, 85% of the 8x8 homes can support this speed. This means less repeaters need to be provisioned for homes with 8x8 APs.

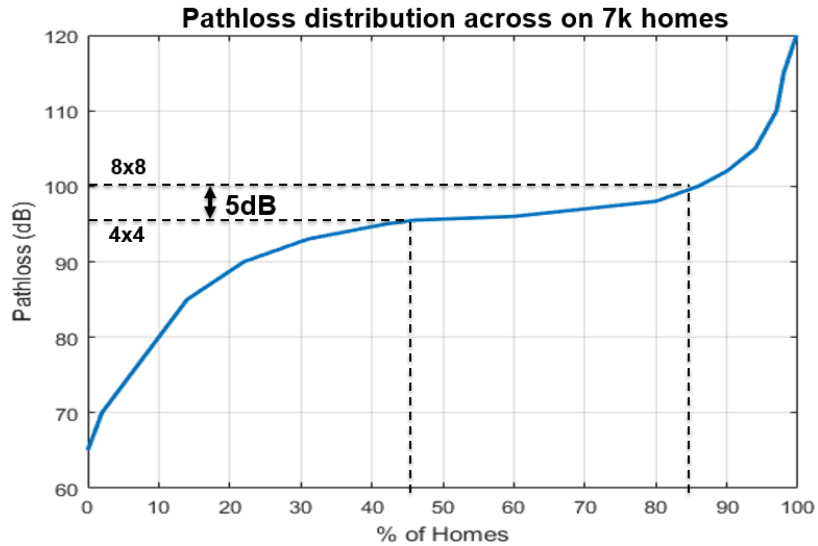

Figure 5. Pathloss distribution (90 percentile) based on 7000 homes. Additional 5dB of serviceable area for 8x8 AP as compared to 4x4 highlighted.

3.2 Single AP Coverage and Rate Gains

Another way to examine the advantages of 8x8 AP over 4x4 AP is to perform a single AP coverage simulation. As an example, the floorplan of Figure 6 is used. The location of the AP is show by a red star. The location of the AP is kept near an outer wall in the garage to emulate a real life scenario. Due to the size of the house, about 23% of the home is disconnected when a 4x4 AP is used, however only about 9% of the home is disconnected when an 8x8 AP is used. The coverage simulation is done using a grid of finely spaced STAs all over the house. A fine grid of points is overlaid on the entire floorplan. Each grid point is taken as a possible location of a station. The per-link RSSI is calculated and if the RSSI is enough to support the lowest MCS, the point is tagged as covered by the AP or AP-repeater group, and tagged as disconnected otherwise. The proportion of coverage area is the ratio of connected grid points to total points in the grid. For the 4000 sqft floor plan shown in Figure 6, approximately 840,000 grid points were used.

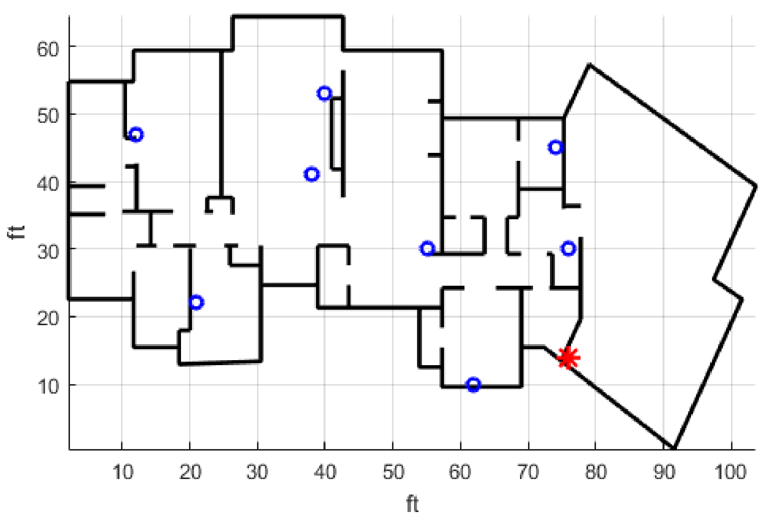

Figure 6. Floorplan of size 4012 sqft with the AP shown as a red star and the STAs shown with blue circles.

In addition to coverage, there is a sizeable speed gain, as shown in Figure 7. On the x-axis, we are showing the gain in the achievable rate when we switch from a 4x4 AP to an 8x8 AP. The y-axis shows what percentage of the floorplan gets such a gain. About 14% of the house that was previously left uncovered by the 4x4 AP can be covered by the 8x8 AP. Additionally, about 24% of the home gets more than 100% gain in the achievable speed test rate (P2P) when we switch to an 8x8 AP.

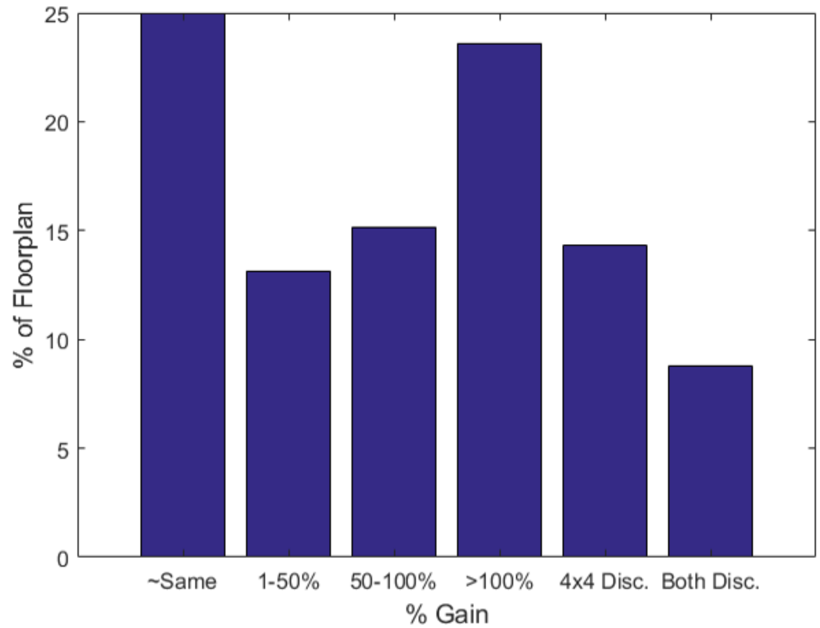

Figure 7. Rate gain of 8x8 AP as compared with a 4x4 AP.

3.2 Single-User and Multi-User Gains with Repeaters

For doing the network capacity calculation, we use a network with three 1x1 STAs each using a 20 Mbps link, three 2x2 STAs each using a 40 Mbps link and two 4x4 STAs each using 100 Mbps links. For such a network setup, we calculate the network throughput supported by the 4x4 and 8x8 APs, when used in conjunction with one or two 2x2 repeaters. In this scenario, the network is used in a half-duplex mode (only one link active at the same time). All the simulation uses downlink traffic. For calculating a single link's capacity, first the traffic routing is calculated. In case of a multi-hop link, the max rate supported is calculated (based on the RSSI and MIMO order supported by the link) in each link and the achievable rate is calculated as the harmonic mean of the rates of each hop. For calculating the sum throughput, airtime is scheduled between all the links (that interfere with each other) using an airtime fairness scheduler at the AP and repeaters (since all traffic is downstream). Using the available airtime and the supported rate, the achieved data rate is calculated for each link. The network capacity is estimated as the sum of the achieved data rate for all the STAs. The network rate comparison is shown in Figure 8. For the 8x8 AP, when there are two repeaters available, the AP-Repeater link can also use MU-MIMO which can not only increase the network capacity, but perform better than just having an AP.

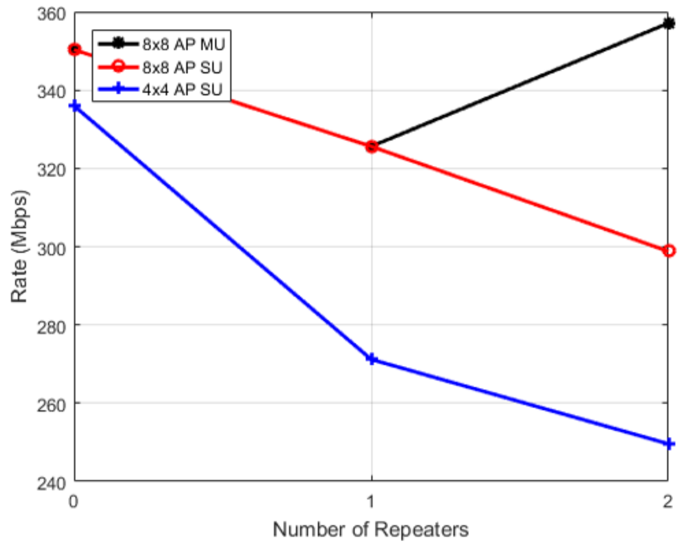

Figure 8. Network rate comparison with 8 STAs.

In fact, it is noticeable that when a 4x4 AP is used, the loss in the network throughput is lot more than when an 8x8 AP is used. The loss is attributed to the lost airtime by the STAs due to the new AP-Repeater link. However, for the 8x8 AP, due to the better supported rate, the airtime loss is less as compare to the 4x4 AP. The degradation in rates due to adding repeaters is summarized in Figure 9.

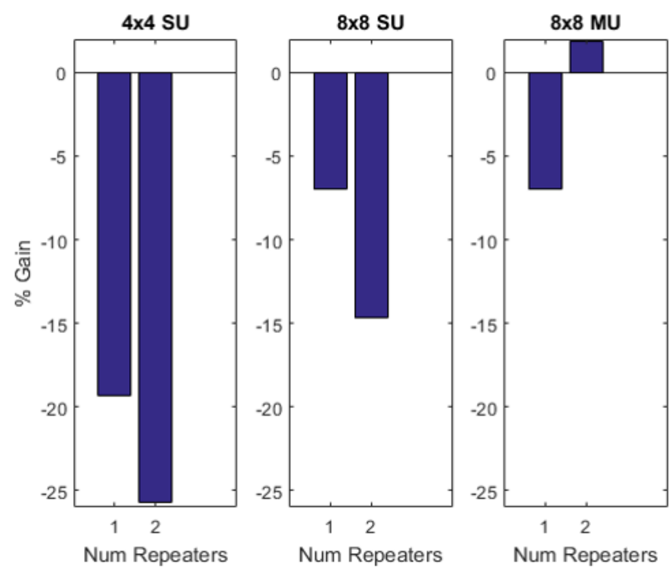

Figure 9. Degradation in rate due to adding half duplex repeaters.

In summary, the 8x8 AP expands the network coverage, which can result in a lower cost since most of the homes won't need a repeater. In the cases when a repeater is needed for coverage reasons, the 8x8 AP will be able to scale better in terms of network capacity and if the repeaters are MU-MIMO compatible, the setup will result in a higher overall system capacity.

4.0 Experimental MU-MIMO Results

In addition to network simulations, extensive real-life performance studies have been conducted inside a test house. In this section, we summarize the MU-MIMO benefits of one such study for an 8x8 AP over 4x4 AP. In recent years, a large number of clients with MU-MIMO capability has been deployed and these include the Samsung Galaxy S8, Google Pixel 1 and 2, Moto Z force, Microsoft Lumia 950, Laptops with Intel 8265 chipsets, and many others. For the purpose of this study, we used an Acer laptop as the client which has the Qualcomm QCA9377 (1x1) chipset. The APs used were based on Quantenna's QSR1000 4x4 and QSR10G 8x8 Wi-Fi chipsets. The clients were distributed at 4 different fixed locations, two of them close to the AP with good RSSI, one mid-range and one farther away as shown in Figure 10.

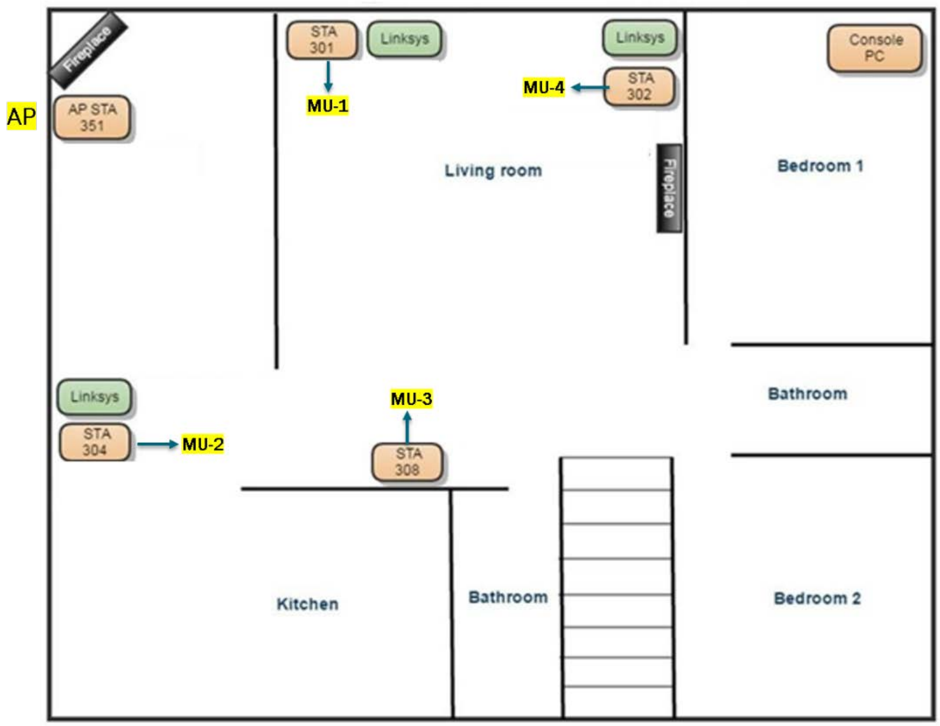

Figure 10. Floorplan with locations of the AP and the four MU capable clients.

Throughput tests were done using all possible combinations of STAs to form MU groups of size 2, 3, and 4 STAs. Measured results are shown in Table 1. The average value for each MU group size is highlighted in the table. With two active clients, the aggregate TCP data rate reached was about 450 Mbps with 4x4 system while the 8x8 system achieves about 600 Mbps which is a 35% improvement. With three active clients, the 4x4 system's throughput decreased slightly to 425 Mbps approximately while the 8x8 system achieves nearly 800 Mbps resulting in an 80% improvement. The limitations of 4x4 MU-MIMO is clearly obvious with the system unable to scale gains. With all clients active, the TCP throughput for the 4x4 system drops to about 385 Mbps while the 8x8 system's throughput is about 850 Mbps resulting in more than 2x gain.

Grouping	ACER Laptop QCA9377 (1X1)	QSR1000 (4x4)		QSR 10G (8x8)	
		UDP	**TCP**	**UDP**	**TCP**
1+1	(L301,L302)	524	446	622	618
	(L301,L304)	530	452	625	558
	(L301,L308)	535	466	631	626
	(L302,L304)	532	473	620	623
	(L302,L308)	504	447	618	612
	(L304,L308)	445	390	627	625
	AVG	**512**	**446**	**624**	**610**
1+1+1	(L301,L302,L304)	364	459	826	789
	(L301,L302,L308)	389	447	821	782
	(L302,L304,L308)	387	422	845	829
	(L301,L304,L308)	364	450	824	803
	AVG	**376**	**444**	**829**	**801**
1+1+1+1	(L301,L302,L304,L308)	**360**	**385**	**905**	**842**

Table 1. UDP and TCP rates for different MU configurations using the Acer 1x1 client with QSR1000 4x4 AP and QSR10G 8x8 AP. All rates are in Mbps in the last four columns. The second column refers to the location of the STAs as shown in Figure 10.

The throughput drop of the 4x4 system with increasing number of clients is due to the need to serve clients farther away resulting in a lower overall throughput. The 8x8 AP not only outperforms the 4x4 version, but scales much better for larger MU group sizes.

5.0 Conclusion

To summarize, the deployment of 8x8 APs significantly increases the data rate over 4x4 AP deployments. Data rate improvements of more than 60% were achieved for houses of 3000 sq.ft. and above, with nearly 24% of the simulated home seeing at least 2x data rate improvements. Additionally, disconnects go down from nearly 23% for a 4x4 deployment to below 10% for 8x8 deployment resulting in 60% decrease in disconnects. It is also shown that MU-MIMO scales better with 8x8 as compared to 4x4. While coverage can be improved by adding repeaters, network capacity goes down due to the half-duplex nature of repeaters resulting in lower capacity as compared to using 8x8 AP in those homes where 8x8 AP provides adequate coverage.

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